AD-A253 135

(2)

REPORT DOCUMENTATION PAGE

0188

Public reporting burden for this collection of information is estimated to average 1 hour ... gathering and maintaining the data needed, and completing and reviewing the collection ... collection of information, including suggestions for reducing this burden, to Washington ... Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and ... ing data sources ... ner aspect of this ... 1215 Jefferson

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 15 July 1992	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE

DoD Space Radiation Concerns

5. FUNDING NUMBERS

RCC - 4020

RCC - 4340

6. AUTHOR(S)

Michael J. Golightly and Daniel L. Collins

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NASA
Johnson Space Center
Houston, TX 77058

Armed Forces Radiobiology
Research Institute
Bethesda, MD 20889-5145

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Armed Forces Radiobiology Research Institute
Bethesda, MD 20889-5145

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

AFRRI 3rd Annual
Program Review

92-19067

11. SUPPLEMENTARY NOTES

DTIC
S ELECTE D
JUL 2 7 1992
C

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

Unlimited

13. ABSTRACT (Maximum 200 words)

Potential manned military space missions would involve exposing crews to many environmental factors, including ionizing radiation. Ionizing radiation in space comes from several natural and man-made sources. Many parameters influence the radiation dose crews would receive and the biomedical outcome of the exposure. A systematic approach has been developed to examine military space crew doses and its impact on mission objectives. The approach involves determining mission and orbital parameters from analysis of preliminary spaceflight operational concepts and objectives, the types of radiation qualities and dose rates to which crews would be exposed, the critical crew functions, and the resulting impact of the projected radiation exposure. From this analysis and a review of the current space radiobiology database, areas requiring further information or research are identified. An initial space radiobiology research program has been outlined. The resulting Space Radiation Effects Study Program has been incorporated into the current DoD 5-Year Plan for Ionizing Radiation Biomedical Research.

14. SUBJECT TERMS

Space Radiobiology, Military Man in Space, Space Radiation Effects, Psychological Stress Effects

15. NUMBER OF PAGES

20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std 239-18
298-102

ABSTRACT

Potential manned military space missions would involve exposing crews to many environmental factors, including ionizing radiation. Ionizing radiation in space comes from several natural and man-made sources. Many parameters influence the radiation dose crews would receive and the biomedical outcome of the exposure. A systematic approach has been developed to examine military space crew doses and its impact on mission objectives. The approach involves determining mission and orbital parameters from analysis of preliminary spaceflight operational concepts and objectives, the types of radiation qualities and dose rates to which crews would be exposed, the critical crew functions, and the resulting impact of the projected radiation exposure. From this analysis and a review of the current space radiobiology database, areas requiring further information or research are identified. An initial space radiobiology research program has been outlined. The resulting Space Radiation Effects Study Program has been incorporated into the current DoD 5-Year Plan for Ionizing Radiation Biomedical Research.

BACKGROUND

The Department of Defense (DoD) is exploring the potential use of military space crews to achieve DoD objectives in space. Numerous paper studies (31) coupled with experiences from the U.S. civil space program are making it increasingly clear that military space crews will be vital to the successful achievement of DoD objectives (25); DoD Space Policy (17) states

> "DoD will actively explore roles for military man in space, focusing on unique or cost effective contributions to operational missions."

To build on previous analyses, DoD has established the Military Man-in-Space (MMIS) Program. Established in 1986, the MMIS Program is to serve as a spaceflight test and evaluation program for military space crew operational concepts (32). All three Services have submitted proposals under the program; the proposals are actively being manifested for flight on board the Shuttle.

Manned DoD space missions could involve national security objectives. Every means must be taken to ensure success of such missions, including understanding the environment crews will operate in and the hazards they will encounter. One hazard in space is ionizing radiation from natural and man made sources. DoD manned space mission scenarios involve radiologically hostile orbits (e.g. polar, geosynchronous) or could face enemy attempts to deny the use of space through radiation environment enhancement. DoD must be able to launch military crews into space and successfully meet objectives, even if hazardous ambient or man-made radiation levels are present. In light of such hazards, military planners, especially within the medical communities, must ask the question "can man meet the Military's needs in space?"

DISCUSSION

Many factors will affect the types of radiations, dose rates, and total doses to which crews will be exposed; these parameters include orbital altitude and inclination, on orbit stay time, temporal position relative to the solar cycle, and use of weapons by an enemy. The outcome of the exposure is also determined by numerous variables including the radiation quality, total dose, dose rate, and the performance demands placed on the crewmen (6,8).

To determine the impact of the space radiation environment on military space crews, a strategy was developed to integrate the numerous factors

involved and assess the impact of the exposure on crew tasks. This strategy, outlined in Figure 1, includes:

1. Define the radiological threat.

2. Define the capabilities that military space crews must be able to perform based on projected mission scenarios.

3. Determine which are the critical aspects of human performance that must be preserved.

4. Determine the impact of the radiological threat on manned operational capabilities.

DEFINING THE RADIOLOGICAL THREAT

Table 1 provides a list of natural and man-made space radiation sources. Defining the radiological threat requires knowledge of the altitude, orbital inclination, and duration of the mission, along with knowledge of the type and amount of shielding present for the crew. Physical characteristics of each source determines the manner in which the dose and dose rate will vary as a function of these factors.

Natural Radiation Sources

The trapped radiation belts have a spatial distribution determined by the shape of the Earth's magnetic field and the energy and charge of the trapped particles. As demonstrated in Figure 2, the trapped radiation belts represent a localized source of radiation. Depending on which portion of the trapped belt is traversed and the temporal position in the solar cycle, doses can vary from 50 μGy (10 μGy=1 mrad) per day to several Gy (1 Gy=100 rad) per day. Galactic Cosmic Radiation (GCR) represents a continuous isotropic low-level source of high energy charged particles. Dose rates can vary from 30 to 300 μGy per day, depending on the temporal position in the solar cycle and the spacecraft position in the Earth's magnetic field. Due to the extreme energy of these particles, fluxes can not be reduced significantly with any reasonable amount of shielding. In fact, the dose behind shielding can increase due to secondary particle production in the material. Solar Particle Events (SPEs) are a highly variable source of radiation. The frequency of these events and the amount, type, and energy of the radiation released exhibit wide variations. Although SPEs have little predictability, they do show some trends with changes in the solar cycle. The dose from these events can very from insignificant to as high as several Gy, depending on the characteristics of the flare, the orbital parameters, and the amount of spacecraft shielding available.

Man-Made Sources of Radiation

Exoatmospheric nuclear weapon detonations present the greatest radiological threat to military space crews. Lack of atmospheric attenuation result in exoatmospheric nuclear weapons being an effective means for destroying space based assets. Unlike terrestrial battlefield use of nuclear weapons, space based targets would be destroyed by energy or electrostatic charge deposition (i.e., from ionizing radiation) and electromagnetic pulses. The radiation component from a weapon detonation includes the prompt radiation from the fission process, and longer duration radiations from "trapping." Because of the low attenuation in space, electrons, produced during the decay of the weapon fissions products, and ionized weapon material can become trapped along the Earth's magnetic field lines. This results in the creation of artificial radiation zones. The dose crewmen will receive from a weapon is a function of the distance from the weapon detonation, number of weapons used, detonation location, weapon yield, time since detonation, amount of shielding available, and the orbital parameters of the

spacecraft. Estimates of total doses range from insignificant to perhaps 200 Gy per day.

Space based nuclear reactors are a manageable source of radiation. Adequate reduction of dose rate can be achieved by shielding, tethering the reactor at a sufficient distance from the spacecraft or allowing sufficient time after reactor shutdown before approaching closely. Unlike terrestrial based reactors, shielding for space reactors face severe weight constraints. Current space reactor shield concepts rely on a wedge shaped shield, referred to as "shadow shields", which would provide a "cone" or "shadow" of shielding to the crew compartment or other critical payloads. Hazardous radiation levels would only be encountered if crewmen were required to approach an operating reactor from behind the shadow shielding (Sholtis 1987, personal communication).

Secondary Particles

The last major source of radiation in space is the secondary particles produced by interactions of the primary radiation with material such as a spacecraft or space suit wall, body, or the atmosphere. The amount and types of the various radiations produced are not completely understood, but are a function of the type and energy of the primary radiation and the amount and composition of the material through which the radiation passes.

Mission parameters which impact the crew radiation dose can be derived from an analysis of DoD manned spaceflight objectives. Table 2 lists potential manned military missions from various paper studies by the U.S. Air Force Space Command and the Strategic Defense Initiative Organization (2,18). Table 3 lists military space crew concept proposals submitted by the Military Services through the MMIS Program (Wortham 1988, personal communication). Areas of interest for surveillance, reconnaissance, oceanic, and weather observations by the Military Services encompass latitudes from the equator to polar regions. The location of potential adversary forces make high latitude observations particularly important. This dictates spacecraft orbital inclinations from 0^{o} to 90^{o}. Likewise, space systems servicing encompasses orbital inclinations from 0^{o} to 90^{o}.

Altitudes for the various proposed manned military space missions also cover a wide range. All missions proposed through the MMIS Program involve some type of visual observation, and will require relatively low orbital altitudes, similar to those currently flown by the Shuttle (250 to 500 Km). Satellite servicing missions envisioned by the Air Force Space Command and the Strategic Defense Initiative Organization would encompass the wide range of orbital altitudes of U.S. space based assets--from low altitudes (200 Km) to the very high altitude at geosynchronous orbit (36,000 Km).

With an understanding of the mission parameters, derived from proposed spaceflight objectives, and characteristics of the space radiation environment, the potential radiological threat to crews can be determined; radiation types and doses are summarized in Table 4. In general, low altitude flights of all inclinations, such as those proposed through the MMIS Program, result in manageable radiation dose rates. Altitudes greater than 2000 Km, such as those more characteristic of satellite servicing missions, can result in substantial dose rates, perhaps several Gy per day. The greatest acute radiological risks result from SPEs and exoatmospheric nuclear weapon detonations. Of considerable interest and concern is the fact these are the most unpredictable radiation sources. In general, doses from SPEs are manageable for orbital inclinations below 50^{o}, due to shielding by the Earth's geomagnetic field. As orbital inclination increases, spacecraft spend a greater portion of each orbit in "free space" over the Earth's poles. Geomagnetic shielding from SPEs is also absent at all inclinations for altitudes of greater than 36,000 Km (i.e., geosynchronous). Outside the geomagnetosphere, doses from SPEs can be substantial, perhaps on the order of 1 to 2 Gy. Doses from exoatmospheric nuclear weapon detonations are a complex function of numerous parameters. Doses could vary from negligible to perhaps 20 Gy per day.

DEFINING CRITICAL SPACE CREW CAPABILITIES AND PERFORMANCE FACTORS

The next step of the analysis is to define the critical tasks the military space crews would be expected to perform, based on the proposed spaceflight objectives. From this, the critical areas of the human body are defined and the impact of the radiation doses can be determined.

All of the proposed missions require either demanding visual observations, fine motor functions (e.g., pointing instruments or extravehicular activity [EVA]) or upper body strength (e.g., EVA). In addition, higher order cognitive processes such as recognition, logical reasoning, and decision making would be required for mission success. Thus, the upper body musculoskeletal system, the central nervous system, the brain and eyes must all be protected from degradation by radiation exposure.

DETERMINING THE IMPACT OF THE RADIOLOGICAL THREAT

The impact on military spacecrews from the derived worst-case radiation doses are summarized in Table 5. The outcome of the exposure depends on numerous variables related to the radiation and the crewmen. The radiation factors include the type, energy, total dose and dose rate of the radiation involved (6,8). Crew variables which effect the outcome of the exposure include the degree of physical demand (24) as well as the complexity of their tasks (8), and the stress experienced by crewmen in meeting required performance standards (8).

As an example, an inverse relationship exists between longevity and physical activity following radiation. Jones et. al. and Kimeldorf and Hunt reported that swimming to exhaustion before and after irradiation significantly reduced rat performance and lowered the LD_{50} (i.e., the lethal dose of radiation to fifty-percent of a population) by about 2 Gy (19,23). Increased mortality was proportional to the number of exercise trials (during the 3 week post-irradiation testing period)(20) and to the dose received (22). More recent data found that rats performing a strenuous motor task postirradiation have a lower LD_{50} compared to animals not required to perform this task (8).

Any dose, no matter how small, carries some risk; exposure should be kept as low as reasonably achievable. The effects of low total doses (i.e., $\leq$ 0.75 Gy) include carcinogenesis (33) and possible neurologic degeneration (21). Although not of immediate concern for mission completion, these effects represent a long-term risk for military crews, are a potential source of liability for the Government (13), and could limit spacecrew participation for repeated missions. At high doses (i.e., $\geq$ 3.0 Gy) (6), effects could range from moderate behavioral changes to severe performance decrement and possible lethality (6,13). Some acute effects of radiation could directly impact critical mission functions, jeopardizing successful mission completion and possibly resulting in loss of spacecraft and crew.

The literature suggests that cognitive impairments, behavioral alterations, and enhanced sympathetic nervous system activation occur when an individual perceives a situation as being potentially threatening and the resources for escaping the threat are inadequate to cope with the circumstances (11). This cascade of psychophysiological activity occurs following the perception of stress, regardless of whether the stressor is of a conventional or radiobiological origin. Inter-disciplinary field research conducted at Three Mile Island (TMI) suggests that individuals, who merely perceived themselves to be exposed to ionizing radiation during the accident and aftermath of TMI, also experienced the cascade of stress impairments. The TMI research findings included decrements of cognitive and behavioral functioning, enhanced sympathetic nervous system involvement (i.e., increased catecholamine production), as well as elevated blood pressures (5,9,10,11,16). These measures were detectable many months after the initial accident. Preaccident blood pressure data was compared to post accident blood pressure data. The blood pressure measures were significantly greater

after the accident than prior to it. Also, the performance and behavioral decrements were greater among the TMI residents than among control subjects located many miles away from TMI. Consequently, since performance decrements are associated with the stress response, per se, an interesting question is, under what circumstances should astronauts be notified of unexpected stressful situations (conventional or radiobiological) that may occur. The potential for solar event radiation at any time during spaceflight, the predicted longer duration missions, and the higher radiation levels associated with planetary exploration, all suggest a need to discuss and resolve this question.

Additionally, the impact of the physiologic and psychological stresses from microgravity must be taken into account in determining the final outcome of the radiation exposure. Insufficient evidence exists at this time to incorporate this factor into the analysis in a quantitative fashion. It is reasonable to assume that these additional stresses will increase the effectiveness of the radiation dose.

There are limits to the applicability of this analysis in determining the scope of the radiological threat to military space crews. Three of the more critical factors, the amount and composition of the shielding available in future military space vehicles or space suits, the range of human variability in response to ionizing radiation exposure, and the impact of microgravity, are currently undetermined. As mission definitions become more finalized and knowledge of the structure of the spacecraft available, improved estimates of the doses and types of radiations to which military crews will be exposed can be made following the procedures currently used by NASA's Space Radiation Analysis Group (SRAG) (3).

In view of the potential consequences, actions must be taken to ensure military space crews can meet their objectives when called upon, even in the face of a radiologically hostile environment. To do this, a thorough understanding of the effects of the various ionizing radiations on humans is required. From this understanding, planners can predict the outcome of the radiation exposure on the the crew and decide if a mission has a sufficient probability of success to warrant execution. Several strategies can be used to reduce the impact of the radiation environment. One solution would be to avoid those orbits and inclinations which are known to present significant risk (such as orbits in the high flux regions of the trapped belts). A second alternative would be to incorporate sufficient shielding, depending on the source of the radiation, into the spacecraft. Where avoidance and shielding are impractical, biomedical methods to mitigate the effects may be the only alternative. Such mitigation techniques could enhance the survivability of crewmen or reduce the behavioral degradation from acute radiation exposures.

SPACE RADIOBIOLOGY RESEARCH REQUIREMENTS

A review of the current space radiobiology database, based on results of the above analysis, has led to the development (by the Armed Forces Radiobiology Research Institute (AFRRI)) of DoD space radiobiology research requirements. Most of the requirements focus on determination of potential radiation doses crews would receive from various space radiation sources, improved radiation measurements, quantifying the effects of acute and chronic exposure to space radiations, investigation into any harmful synergisms from exposures while in microgravity, and methods to preserve the health and performance of the crews. These requirements, listed in Table 6, have been endorsed by the Office of the Air Force Surgeon General (35).

SPACE RADIATION EFFECTS STUDY PROGRAM

A Space Radiation Effects Study Program has been designed by AFRRI to address these research requirements. The Study Program, outlined in Table 7, is comprised of five basic areas: acute medical effects, performance management, microgravity synergism, space radiation environment characterization, and operational support. A basic premise in designing the

program is that much of the radiobiology of acute radiation exposure and the long-term effects from heavy ion exposure that has been done or is currently in progress is relevant to the space radiobiology problem. This program has not sought to duplicate these efforts. Instead, the Study Program is designed to examine the major unanswered space radiobiology questions relevant to manned military missions. Particular attention has been placed on the radiobiology of protons and high charge, high energy (HZE) particles; relatively little relevant radiobiology data exists currently. The Study Program has been incorporated into the FY 89-93 DoD 5-Year Plan for Ionizing Radiation Biomedical Research.

Any DoD program in space radiobiology should be closely coordinated with NASA. Coordination of DoD and NASA research efforts are required to derive maximum benefit and minimal duplication of invested resources. However, DoD cannot rely completely on NASA to provide all of its space radiobiology research. NASA can avoid or delay missions which may present an unreasonable risk to astronauts. Conversely, not all DoD space objectives would permit delay or avoidance until benign radiological conditions exist. DoD must be ready to launch a manned military mission, despite radiation conditions, if requirements dictate.

The Study Program also proposes development of a DoD Space Radiation Analysis Group (SRAG). One approach to the composition, structure and function of such a group is shown in Figure 3. The role for this group would be to apply the space radiobiology database to operational problems, using an analysis similar to that outlined in Figure 1. The responsibility of this group would be to interpret mission operational requirements, determine if the projected radiation environment would preclude or limit the objectives, establish credible worst-case scenarios and develop contingency plans to ensure completion of the mission. The group would also monitor the radiation environment and crew performance during a mission and recommend countermeasures or corrective actions, as necessary, to the operational commander. A basis for development of this group could be NASA's SRAG at the Lyndon B. Johnson Space Center.

CONCLUSIONS

A strategy has been developed to assess the radiological impact on military crewmen based on military spaceflight objectives. From the analysis, it can be seen that the types of radiation of importance encompass charged particles from electrons to HZE particles such as iron, uncharged particles such as photons and neutrons, and other subatomic particles. Dose and dose rates vary from low, manageable amounts, to subacute and possible lethal exposures.

Unresolved questions regarding the magnitude of the radiological threat and the impact on crew health and performance remain. To find solutions to these problems, a Space Radiation Effects Study Program has been designed and incorporated into the current DoD 5-Year Plan for Ionizing Radiation Biomedical Research. Maximum benefit from such research will be realized if an analysis group is established, such as a DoD SRAG, to convert the research data into guidance and recommendations to support operational space mission commanders. DoD efforts should not be undertaken in a vacuum. Close coordination between DoD and NASA will avoid unnecessary duplication of efforts, conserve valuable research funds, and maximize return on investments by combining talents and expertise.

REFERENCES

1. Armstrong TW, Alsmiller RG Jr., Chandler KC. Monte carlo calculations of high-energy nucleon-meson cascades and applications to galactic cosmic-ray transport. NASA TM X-2440, 1972:117-122.

2. Atkins SG, Small JT, McFarland TM. Military Man-in Space (MMIS) Program. Proceedings of the Space Radiobiology Program Review (In press).

3. Atwell W, Beever ER, Hardy AC, Cash BL. A radiation shielding model of the space shuttle for space radiation dose exposure estimations. In: Hall ML, ed. Proceedings of the ANS Topical Meeting on Advances in Nuclear Engineering Computation and Radiation Shielding, 1989, 11:1-12.

4. Bailey P. Neutron radiation dosimetry in high altitude flight personnel. Aviat. Space Environ. Med., 1982, 53:808-17.

5. Baum A, Schaeffer M, Lake R, Fleming R, Collins DL. Psychological and endocrinological correlates of chronic stress at Three Mile Island. In:Williams R, ed. Perspectives on Behavioral Medicine, Vol 2, 1985:201-217.

6. Baum SJ, Anno GH, Young RW, Withers HR. Nuclear weapon effect research at PSR-1983, volume 10-symptomatology of acute radiation effects in humans after exposure to doses of 75 to 4500 rads (cGy) free-in-air. DNA-TR-85-50, 1984.

7. Benton EV, Parnell TA. Space radiation dosimetry on U.S. and Soviet manned missions. In:McCormack PD, Swenberg CE, Bucker H, eds. Terrestrial Space Radiation and Its Biological Effects. New York:Plenum Press, 1988:729-794.

8. Bogo V. Radiation: behavioral implications in space. Toxicology, 1988, 49:299-307.

9. Collins DL. Persistence differences between Three Mile Island residents and a control group. Defense Technical Information Center, Cameron Station, Alexandria, VA, 22304, AD A145567, 1984.

10. Collins DL. Psychological issues relevant to astronaut selection for long-duration spaceflight: a review of the literature. AFHRL-TP-84-41 (National Technical Information Service, Springfield, VA, 22161, AD-A154-056), April 1985.

11. Collins DL, Baum A, Singer JE. Coping with stress at Three Mile Island: Psychological and biochemical evidence. Health Psychology, June 1983, 2(2):149-166.

12. Collins DL, Baum A, Singer JE. Three Mile Island: the effects of coping styles and involvement on perceived control. Presented at the Annual Convention of the American Psychological Association, Toronto, Canada, 24-28 August 1984.

13. Conklin JE, Walker RI. Military radiobiology: a perspective. In:Conklin JE, Walker RI, eds. Military Radiobiology. New York: Academic Press, 1987.

14. Curtis SB. Radiation physics and evaluation of current hazards. In:Tobias CA, Todd P, eds. Space Radiation Biology and Related Topics. New York: Academic Press, 1974:21-99.

15. Curtis SB, Atwell W, Beever R, Hardy A. Radiation environments and absorbed dose estimations on manned space missions. Adv. Space Res., 1986, 6:269-74.

16. Davidson LM, Baum A, Collins DL. Stress and control-related problems at Three Mile Island. J. of Appl. Social Psychology, 1982, 12(5): 349-359.

17. Department of Defense (DoD). Space policy (U), 10 Mar 1987.

18. Ely N. Preliminary SDI support concepts. Presented at the 3rd Pathways to Space Experimentation Workshop, Orlando, FL, 02-04 Jun 1987.

19. Jones DC, Kimeldorf DJ, Rubadeau DO, Castanero TJ. The relationship of radiation dose to lethality among exercised animals exposed to roentgen rays. Am. J. Physiology, 1951, 167:626-632.

20. Jones DC, Kimeldorf DJ, Rubadeau DO, Castanero TJ. Relationship between volitional activity and age in the male rat. Am. J. Physiology, 1953, 172:109-114.

21. Joseph JA, Hunt WA, Rabin BM, Dalton TK. Correlative motor behavioral and striatal dopaminergic alterations induced by ^{56}Fe radiation. In:McCormack PD, Swenberg CE, Bucker H, eds. Terrestrial Space Radiation and Its Biological Effects. New York:Plenum Press, 1988:553-571.

22. Kimeldorf DJ, Jones DC, Castanero TJ. Effect of x-irradiation upon the performance of daily exhaustive exercise by the rat. Am. J. Physiology, 1953, 174:331-335.

23. Kimeldorf DJ, Hunt EL. Ionizing radiation: neural function and behavior. New York: Academic Press, 1965.

24. Kovalev EE. Radiation protection during spaceflight. Aviat. Space Environ. Med., Suppl. 1., 1983, 54:S-16-23.

25. Lantham DC. A prescription for America's galaxy of problems in space. Armed Forces J. Intl., Sept 1987:42-50.

26. Lett JT, Cox AB, Lee AC. Selected examples of degenerative late effects caused by particulate radiations in normal tissue. In:McCormack PD, Swenberg CE, Bucker H, eds. Terrestrial Space Radiation and Its Biological Effects. New York:Plenum Press, 1988:393-413.

27. Payton G. Strategic Defense Initiative missions. Proceedings of the Space Radiobiology *Program Review (In press)*.

28. Santoro RT, Claiborne HC, Alsmiller RG Jr. Primary- and secondary-particle contributions to the depth-dose distribution in a phantom shielded from solar-flare and Van Allen protons. NASA TM X-2440, 1972:128-136.

29. Silberberg R, Tsao CH, Adams JH Jr., Letaw JR. Radiation doses and LET distributions of cosmic rays. Rad. Res., 1984, 98:209-226.

30. Stauber MC, Rossi ML, Stassinopoulos, EG. An overview of medical-biological radiation hazards in earth orbits. In:Heath GW, ed. Space Safety and Rescue 1982-1983 (IAA 83-256), Science and Technology Series, 1983:267-301

31. U.S. Air Force Space Command (AFSPACECOM)/DCS Plans. The utility of military crews in space, 30 Dec 1985.

32. U.S. Air Force Space Command (AFSPACECOM)/XPSS. Military man-in-space handbook, Feb 1988.

33. Wood DH, Pickering JE, Yochmowitz MG. Radiation risk assessment for military space crews. Mil. Med.,1988, 153(6):298-303.

34. Young RW, Meyers PH. The human response to nuclear radiation. Med. Bull., 1986, 43(7):20.

35. U.S. Air Force Surgeon General letter, 29 Jan 1988.

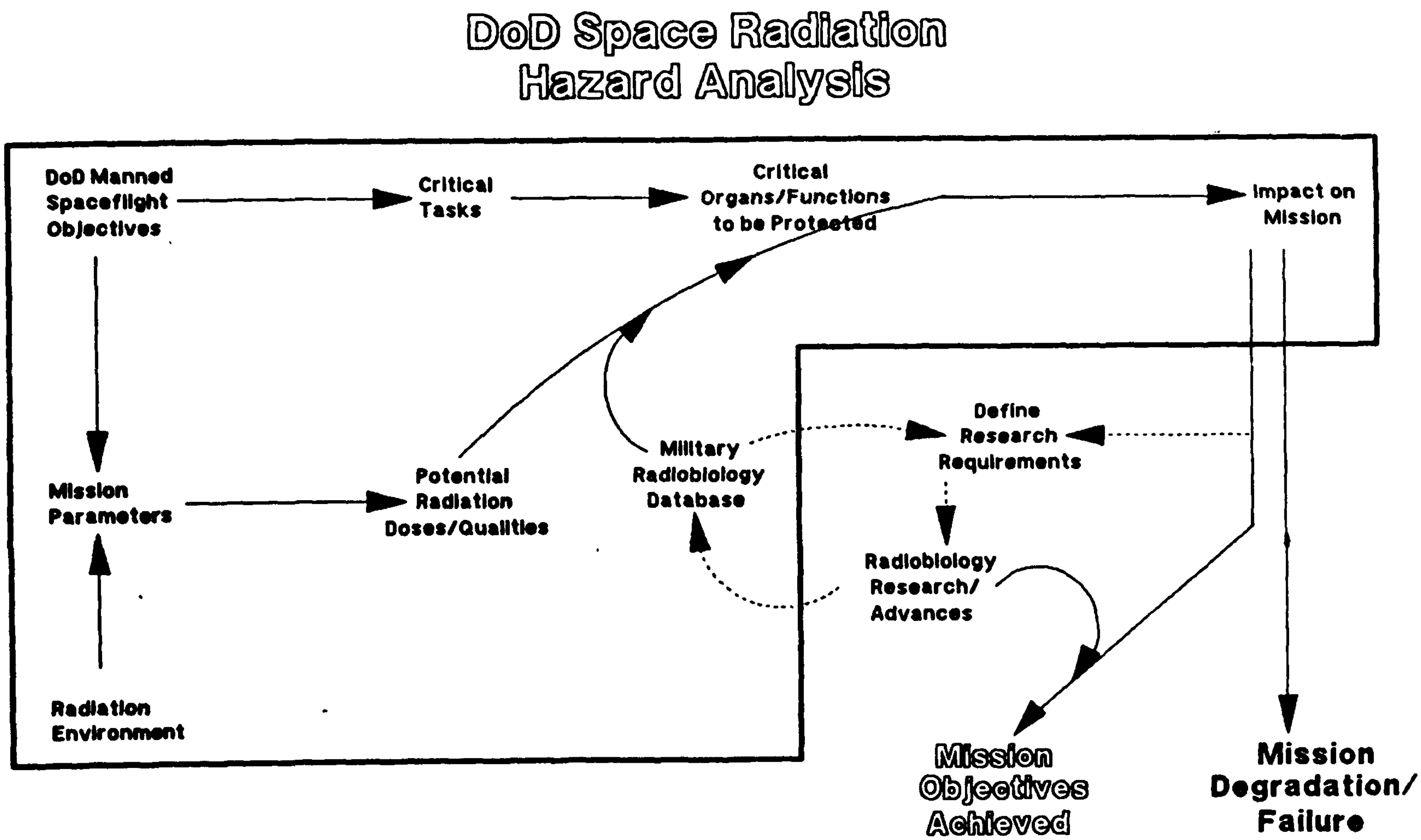

Figure 1. Flow diagram representing analysis of radiation hazards to military space crews. The areas within the heavy border represent the components included in the analysis.

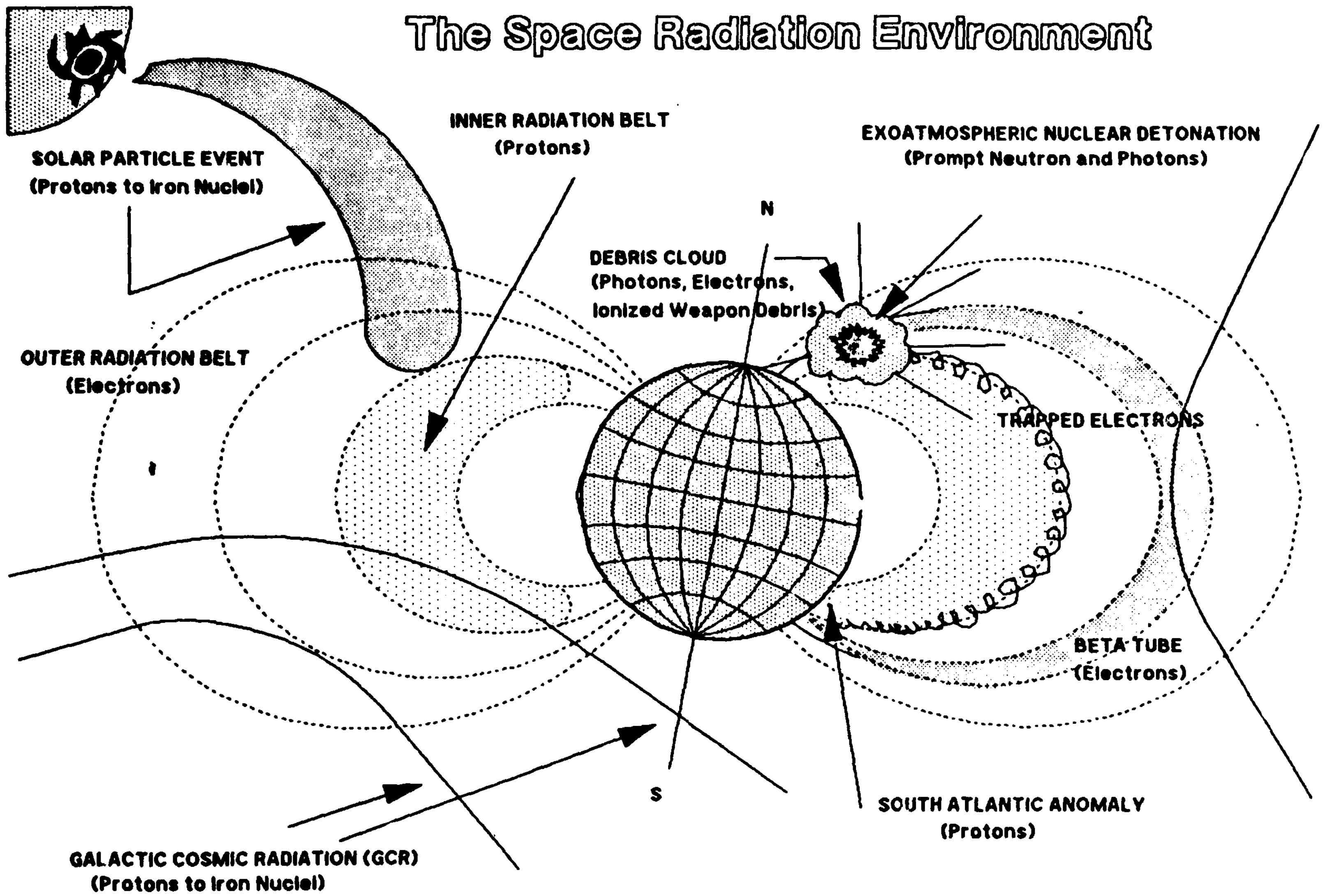

Figure 2. Representation of the major sources of ionizing of importance to manned military space missions. Note the spatial distribution of the trapped radiation belts.

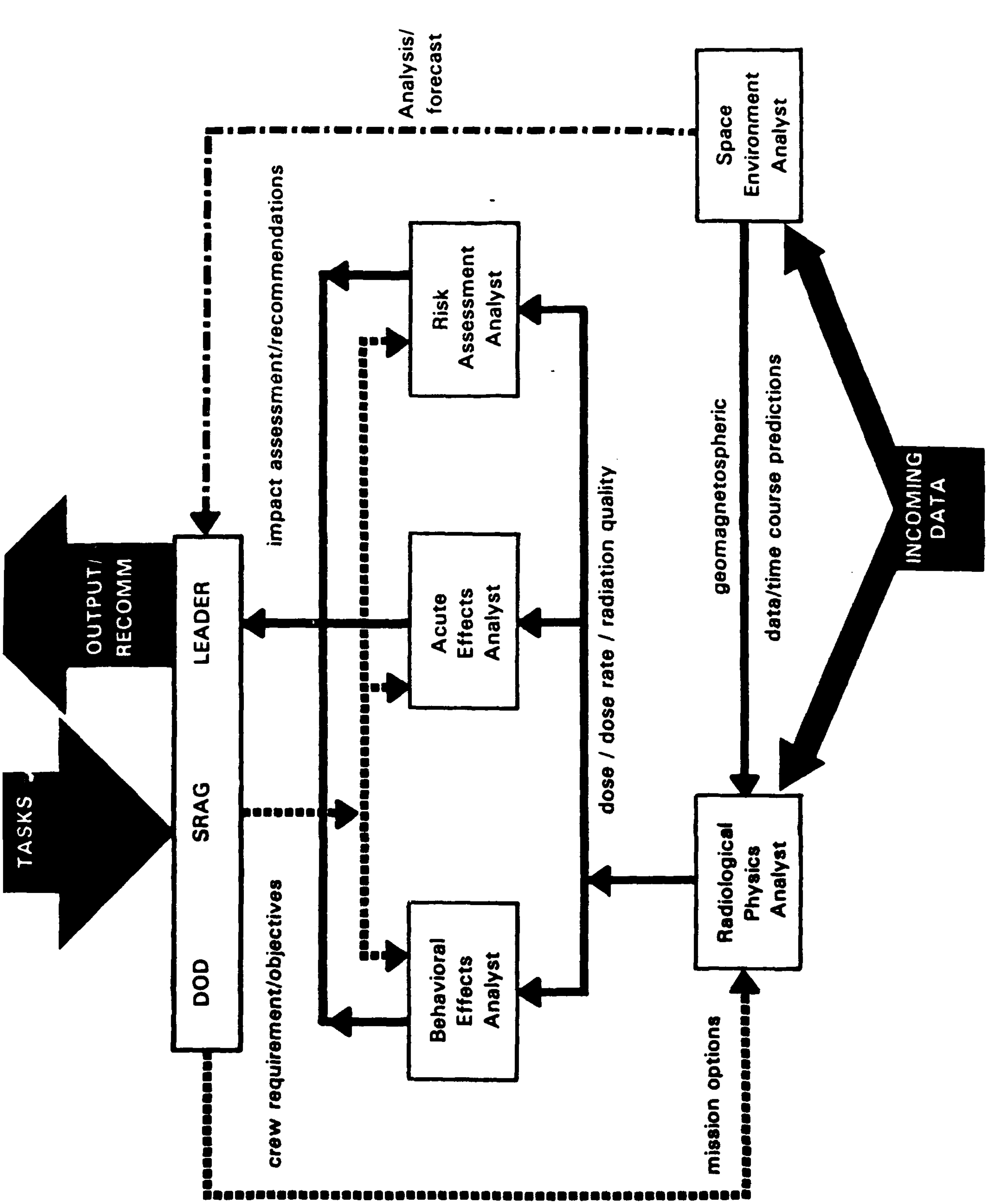

Figure 3. A diagram for a DoD Space Radiation Analysis Group (SRAG). A SRAG would be composed of military officers trained in the various aspects of radiobiology important to manned military space operations. A DoD SRAG would serve an important role by advising operational space commanders on the impact of enhanced radiation levels on mission success and completion.

Natural Radiation
Trapped Radiation Belts
Galactic Cosmic Rays (GCR)
Solar Particle Events (SPEs)
Man-Made Sources of Radiation
Exoatmospheric Nuclear Weapon Detonations
Space-Based Nuclear Reactors
Secondary Particles Produced in Material
Structural Shielding
Body
Atmosphere

Table 1. The sources of ionizing radiation exposure of importance to manned spaceflight. The acute radiological threats are solar particle events and exoatmospheric nuclear weapon detonations. The remaining sources of radiation may be considered chronic to subacute hazards (Armstrong et. al. 1972; Bailey 1982; Curtis 1974; Santoro et. al. 1972; Silberberg et. al. 1984; Stauber et. al. 1983).

MICROGRAVITY SYNERGISM

Determine the impact of physiological changes from exposure to microgravity on the biological effects of radiation exposure:

- o Investigate potential radiation effect-microgravity synergism using ground-based laboratory animal models.
- o Quantify the magnitude of a microgravity-radiation effects synergism through non-routine spaceflight experiments utilizinging radiation sources aboard the spacecraft.
- o Quantify the effect of microgravity on the immune system.
- o Develop pharmacologic agents to counteract microgravity induced immune system depression.

OPERATIONAL SUPPORT

Develop guidance for and provide support to operational military space mission commanders:

- o Develop treatment regimens and criteria for a suitable facility to treat acutely exposed military crewmen.
- o Develop radiation protection concepts and doctrine for acute radiation exposure of military crewmen.
- o Develop a comprehensive space radiation effects guide for operational military space commanders.
- o Develop a DoD Space Radiation Analysis Group (SRAG) to provide real-time support to military space commanders.
- o Develop a course for military flight surgeons and aviation physiologists in the hazards of space radiation.
- o Provide a Statement of Need (SON) to the Armed Forces Medical Intelligence Center (AFMIC) to develop and maintain a foreign space medicine technology database.

FORCE ENHANCEMENT	SPACE CONTROL	FORCE APPLICATION
Strategic Defense	Satellite Servicing Under Duress	Contingency Missions
Contingency Missions	Retrieval	
Intelligence Gathering	Refurbishment	
Space Object Identification	Maintenance	
Space Environment Forecasting		
Weather Support		

Table 2. Examples of potential military manned space missions derived from results of various paper studies (Atkins, et al. 1987; Ely 1987; Payton 1987).

AIR FORCE

SPADVOS (HSD)- Allow direct view, real-time enhanced observation of terrestrial surface or airborne features of interest. (2/11; 4/40)

MOATTER (AFSPACECOM)- Test man's ability to acquire, track, and film various moving targets on or near the Earth's surface. (10/11; 38/40)

SPACE DEBRIS (AFSPACECOM)- Evaluate man's potential for operational characterization of space objects and debris belts. (11/11; 39/40)

WEATHER OFFICER IN SPACE (MAC)- Evaluate the potential for operational space environmental support from a very high inclination orbit. (7/11; 22/40) [Requires Payload Specialist]

SPACE DESIGNATION (SEILER)- Evaluate man's ability to acquire, track, and lase an instrumented surface target. (8/11; 33/40)

BATTLE VIEW (AFSPACECOM)- Evaluate an astronaut's ability to perform battlefield surveillance using hand-held optical devices (5/11; 20/40)

NAVY

LAT/LON (NAVSPACECOM)- Evaluate a space sextant system for determining the surface location of oceanographic and meteorological phenomina. (1/11; 1/40)

MOSES (OPNAV)- Conduct a series of specific experiments to determine the range of intelligence and tactical exploitation of national capabilities (TENCAP) applications of astronauts in space. (4/11; 9/40)

NIGHT MIST (NAVSPACECOM)- Classified experiment. (3/11; 8/40)

ARMY

TERRA SCOUT (ICSSO)- Classified Experiment. (6/11; 21/40) [Requires Payload Specialist]

TERRA GEODE (USACE)- Evaluate human ability to interpret geologic landforms with regard to ground combat operations. (9/11; 34/40)

Table 3. Proposed military manned space mission operational concepts proposed through the DoD Military Man in Space (MMIS) Program. The purpose of the MMIS Program is to "exploit the military potential of using the space environment to apply man's unique powers of observation and decision making." All three services are actively participating in the MMIS Program. These experiments are currently being manifested for spaceflight. The sponsoring command or agency is identified in parenthesis after the experiments name. The two sets of numbers in parenthesis at the end of each experiment's description are the ranking of the experiments from the DoD MMIS Prioritization Board and the DoD Space Test Program (STP) Board. As an example, SPADVOS was ranked 2nd of 11 experiments at the DoD MMIS Prioritization Board and 4th of 40 experiments at the STP Board.

Protons	50 μGy/day	------->	3 Gy/day
Neutrons	10 μGy/day	------->	2 Gy (prompt)
Photons	10 μGy/day	------->	2 Gy (prompt)
HZE	30 μGy/day	------->	300 μGy/day
Electrons	10 μGy/day	------->	200 Gy/day
Pions		?	
Muons		?	
Positrons		?	
Kaons		?	

Table 4. The types of radiation, total doses and dose rates which military space crews must be prepared to encounter during spaceflight. Values to the left of the arrow represent reasonable minimum values. Values to the right of the arrow are estimates of maximum values for credible worst-case scenarios (Armstrong et. al. 1972; Bailey 1982; Benton and Parnell 1988; Curtis 1974; Curtis et. al. 1986; Kovalev 1983; Santoro et. al. 1972; Silberberg et. al. 1984; Stauber et.al. 1983).

Acute
Sublethal to Lethal Whole Body Doses
Cognitive Deficit
Emesis
Loss of Upper Body Strength
Impairment of Fine Motor Control
Full Thickness Skin Burns
Retina Destruction
Immune System Impairment
Radiation Pneumonitis
Long Term
Carcinogenesis
Cataractogenesis
Ocular Atrophy
Permanent Neurologic Degradation

Table 5. The adverse biological effects crews would experience in space. The outcome depends on the total absorbed dose, dose rate, and type (quality) of the radiation involved. Some of the high-LET radiations present, such as neutrons and HZE particles, appear to have a significantly increased effectiveness at cancer induction relative to low-LET radiations such as photons and protons (Baum et. al. 1984; Bogo 1988; Conklin and Walker 1987; Joseph et. al. 1988; Lett et. al. 1988; Wood et. al. 1988; Young and Meyers 1988)

Characterize and Quantify Space Radiation Doses to Military Space Crews

-Determine doses received by crews inside space craft or EVA suits from exo-atmospheric weapons bursts.

-Determine doses received by crews inside space craft or EVA suits from Anomalously Large Solar Particle Events (AL SPEs).

-Develop biological dosimetry methods to quantify exposure to the various space radiations.

-Develop accurate passive and active physical dosimetric methods to measure radiation components and doses inside space craft and EVA suits.

-Characterize the nominal radiation environment inside space craft and EVA suits.

Medical Effects and Treatment of Military Space Crews Exposed to Space Radiations

-Identify, evaluate and formulate radioprotectants for space flight use.

-Develop methods for medical treatment of radiation injury in space flight.

-Quantify and preserve crew performance from acute and chronic radiation exposures in space.

-Investigate and quantify the biological effects of radiation particles present inside space craft and EVA suits.

-Quantify the long term effects and risks from radiation exposure during space flight.

-Investigate, quantify and develop means to mitigate any harmful synergistic actions between space radiation damage and microgravity effects.

-Develop radiation protection concepts and doctrine for manned military space flight.

Table 6. Department of Defense Space Radiobiology Research Requirements. This list is a compilation of radiobiological questions that need to be answered or biotechnology that needs to be developed for successful completion of manned DoD space missions.

ACUTE MEDICAL EFFECTS

Characterize the medical effects of acute space radiation exposures:

- o Determine the pathology and relative biological effectiveness of acute proton exposure.
- o Identify the pathogenesis of ocular damage from exposure to fission spectra beta particles and resulting bremsstrahlung radiation. Determine the kinetics of damage manifestation.
- o Develop radioprotectant(s) to enhance survivability and maintain skin and ocular function after acute radiation exposure.

SPACE RADIATION ENVIRONMENT CHARACTERIZATION

Characterize the radiation environment inside military spacecraft and space suits:

- o Calculate doses and radiation quality to critical biological structures from exoatmospheric nuclear weapon detonations.
- o Measure and evaluate the natural radiation environment inside spacecraft/space suits and at critical organs in the body.
- o Develop improved active and passive dosimetry systems.

PERFORMANCE MANAGEMENT

Characterize the behavioral effects of sub-acute to acute radiation exposures in space and its impact on manned space missions:

- o Determine the behavioral effects of HZE particles, protons, and neutrons with energies characteristic of those found inside spacecraft. Determine if a dose rate effect exists.
- o Determine the impact of radiation damage to the skin and eyes on crew performance.
- o Quantify the impact of space radiation exposure on crew task completion.
- o Develop behavioral radioprotectants for use in military space missions.

Table 7. Proposed Space Radiation Effects Study Program. The program was developed with consideration of the importance of acute radiation effects on military mission completion.